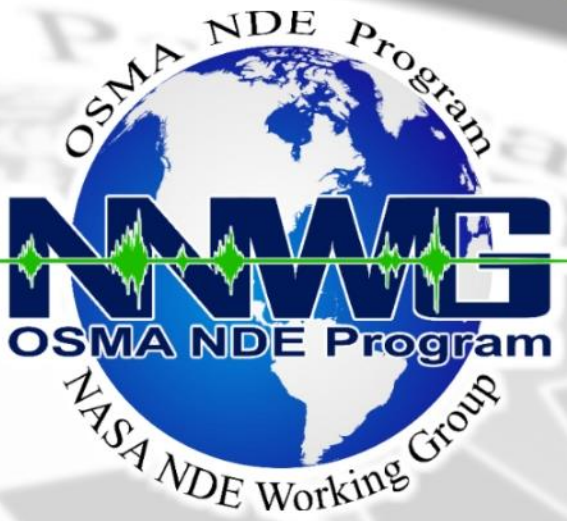


Transition of OSMA AM Responsibility from WSTF to MSFC

Jess Waller

NASA Johnson Space Center - White Sands Test Facility

NESC NDE TDT Annual Review Meeting – May 14-15, 2019

Additive manufacturing (AM) is a rapidly evolving, game changing technology requiring many disciplines (including NDE) to ensure mission safety and reliability.

SIPPING WATER

From A Fire Hydrant

HERDING CATS

There's No Feeling Quite Like It

While AM is becoming increasingly democratized and pervasive, managing risks for fracture critical L-PBF spaceflight hardware must clearly come from MSFC.

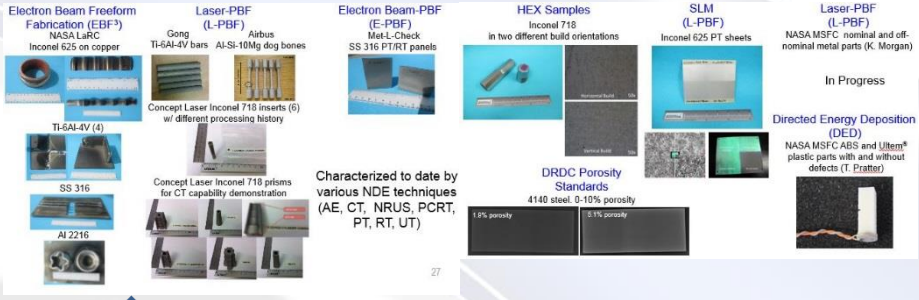
Background

- Activities stemming from a three-year OSMA NDE Program project are being transitioned to MSFC. The project had two parts:
  1. **Effect-of-Defect of Unique Laser PBF Flaw Types: NASA-Industry Round Robin Study**
  2. **NDE of Aerospace Materials VCO Standards**
- Early in the project, it became apparent AM parts could be made by industry at little or cost to NASA, facilitated by a request made to industry by America Makes/Jim Morris seeking volunteers to make parts with known defects or process variation.
- The initial plan to make only L-PBF parts (University of Louisville, Airbus, Incodema3D, UTC) was expanded to include parts made by 3 other manufacturing processes: 1) laser-cused L-PBF (Concept Laser/GE), 3) EBF3 DED (NASA LaRC), and 4) EB-PBF (CalRAM).
- Funding originally allocated for WSTF destructive and nondestructive testing was reallocated to support rapidly evolving Scope changes:
  - America Makes/ANSI AM Standardization Collaborative roadmapping activities (2017, 2018)
  - NASA/ESA/JAXA trilateral AM collaboration telecons and annual meetings (2015, 2016, 2018)
  - QLF annual meetings (2016, 2017, 2018)
  - ASTM F42/E07/E08 Symposium on Structural Integrity of AM Parts support (co-chair, Nov. 2018)
  - NASA and ASTM webinars and courses on NDE-based QA of AM Parts (2017, 2018, 2019)
  - Recent: transition NDE of AM standardization and testing efforts to MSFC

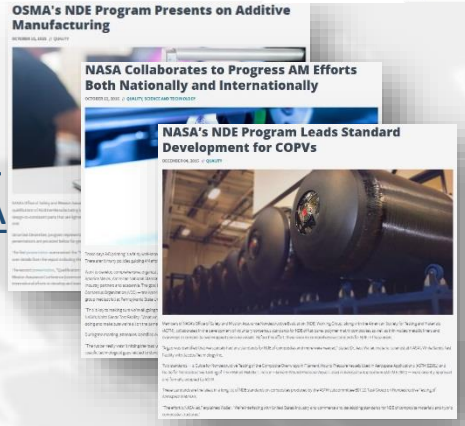
FY17-19 Overview of OSMA Project

Engage in international partnering

Lead NASA-industry round robin tests and effect-of-defect studies

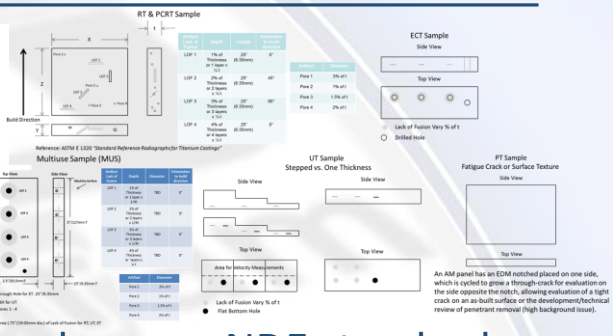


Courses, Webinars, and OSMA Publicity

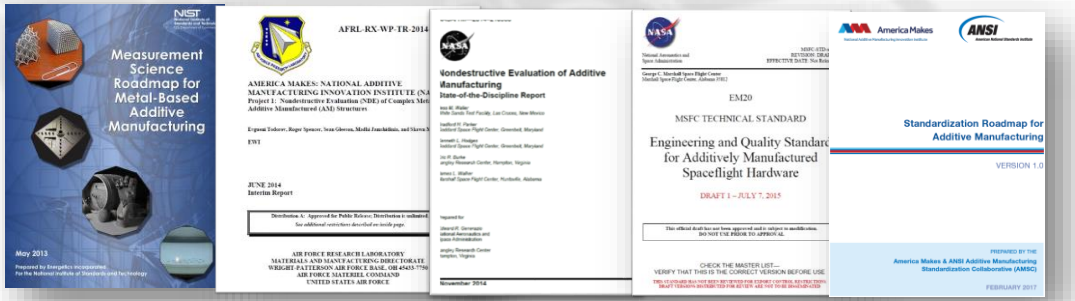


OSMA NDE Program VCO Standards and AM Foundational Efforts

Develop physical ref. stds. and phantoms with seeded flaws



Integrate and Implement NASA and non-NASA guidance



Develop new NDE standards

FY19 Additive Manufacturing-related OSMA Products

(to be transitioned to MSFC)

Highlight - NDE of AM Voluntary Consensus Standard Guide

ASTM WK47031 Standard Guide Status:

- *Goal*: provide basic instruction for surface and volumetric inspection
- PBF/DED focus (L and EB)
- Covers CT, ET, MET, PCRT, PT, RT, TT, and UT
- May consider a RAM section for WK47031 after adoption (needs vetting by E07.06)
- NDE round robin testing was conducted in conjunction with development of this standard
- Balloted in E07.10 S/C June and August 2017; concurrently balloted in May and December 2018
- Last round of negatives were minor
- **In concurrent balloting: April 30th to May 30th**
- POC: Jess Waller/NASA WSTF


Designation: X XXXX-XX

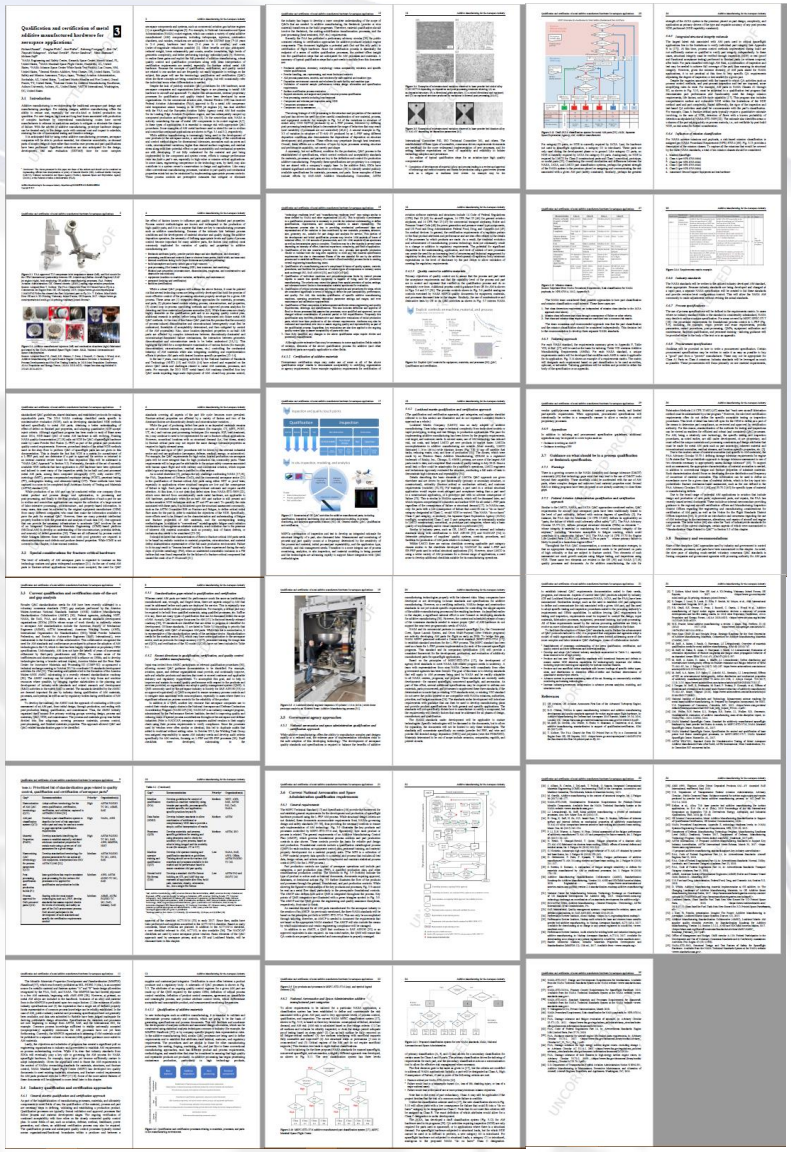
Work Item Number: 47031
Date: April 26, 2019

Standard Guide for Nondestructive Testing of Metal Additively Manufactured Aerospace Parts After Build[1]

https://www.astm.org/WorkItems/WK47031.htm

Highlight - Book Chapter in *Additive Manuf. for the Aerospace Industry*

Russell, R., Wells, D., Waller, J., Poorganji, B., Ott, E., Nakagawa, T., Sandoval, H., Shamsaei, N., Seifi. M., "Qualification and Certification of Metal Additive Manufactured Hardware for Aerospace Applications," Chapter 3, in *Additive Manufacturing for the Aerospace Industry*, Boyer and Froes, Eds., Elsevier, December 2019. https://www.elsevier.com/books/additive-manufacturing-for-the-aerospace-industry/froes/978-0-12-814062-8



Highlight - 3rd ASTM Symposium on Structural Integrity of AM Parts

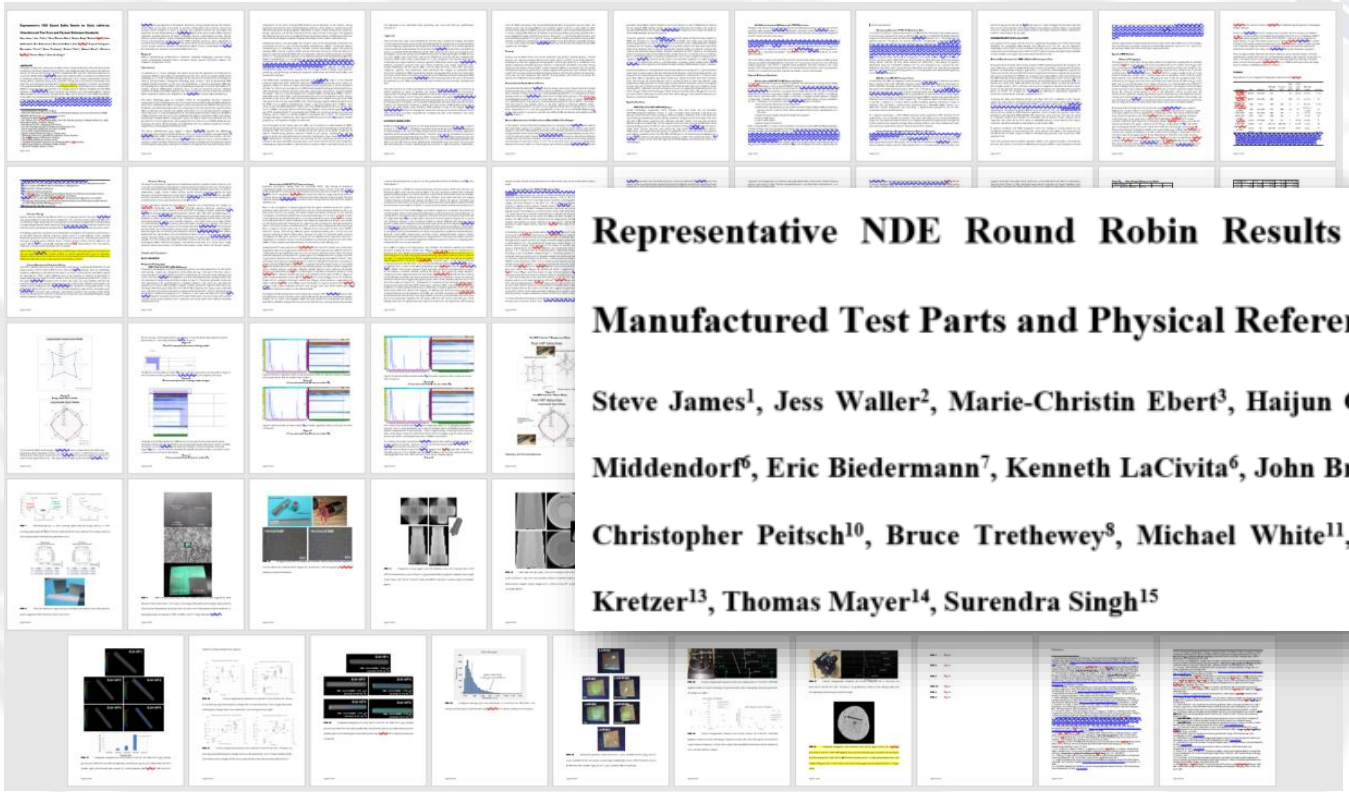
Four papers/five presentations given (as part of ASTM Round Robin Testing):

1. Dutton , B., Vesga, W., Waller, J., James, S., and Seifi., M., “Additive Manufacturing Defect Formation and NDE Detectability,” in ASTM Symposium on Structural Integrity of Additive Manufactured Parts, ASTM STP 1620, M. Seifi and N. Shamsaei, Eds., ASTM International, West Conshohocken, PA (in press).
2. Na, J. K, Middendorf, J., Lander, M., Waller, J. M., “Nondestructive Evaluation of Programmed Defects in Ti-6Al-4V L-PBF ASTM E8 compliant Dog-bone Samples,” in ASTM Symposium on Structural Integrity of Additive Manufactured Parts, ASTM STP 1620, M. Seifi and N. Shamsaei, Eds., ASTM International, West Conshohocken, PA (in press).
3. Livings, R. A., Biedermann, E. J., Wang, C., Chung, T., James, S., Waller, J. M., Volk, S., Krishnan, A., Collins, S., ”Nondestructive Evaluation of Additive Manufactured Parts Using Process Compensated Resonance Testing,” in ASTM Symposium on Structural Integrity of Additive Manufactured Parts, ASTM STP 1620, M. Seifi and N. Shamsaei, Eds., ASTM International, West Conshohocken, PA (in press).
4. Waller, J. M., Nichols, C. T., Burke, E. R., Wells, D. N., Brandão, A. D., Gumpinger, J., Born, M., Ghidini, T., Nakagawa, T., Koike, A., Mitsui, M., Itoh, T., “NDE-Based Quality Assurance of Metal Additive Manufactured Aerospace Parts at NASA, JAXA, and ESA,” in ASTM Symposium on Structural Integrity of Additive Manufactured Parts, ASTM STP 1620, M. Seifi and N. Shamsaei, Eds., ASTM International, West Conshohocken, PA (in press).

https://www.astm.org/3rdAMSymposium.pdf (1228-slide presentation compendium available to attendees)

Fifth paper summarizing Round Robin Test findings has taken longer to complete (currently in review):

5. Steve James, Jess Waller, Marie-Christin Ebert, Haijun Gong, Richard Grylls, John Middendorf, Eric Biedermann, Kenneth LaCivita, John Brausch, Tsuyoshi Nakagawa, Christopher Peitsch, Bruce Trethewey, Michael White, Edward Ginzel, Christian Kretzer, Thomas Mayer, Surendra Singh, "Representative NDE Round Robin Results on Metal Additively Manufactured Test Parts and Physical Reference Standards," *Material Performance and Characterization*, ASTM International, West Conshohocken, PA (in review).



Representative NDE Round Robin Results on Metal Additively Manufactured Test Parts and Physical Reference Standards

Steve James[1], Jess Waller[2], Marie-Christin Ebert[3], Haijun Gong[4], Richard Grylls[5], John Middendorf[6], Eric Biedermann[7], Kenneth LaCivita[6], John Brausch[8], Tsuyoshi Nakagawa[9], Christopher Peitsch[10], Bruce Trethewey[8], Michael White[11], Edward Ginzel[12], Christian Kretzer[13], Thomas Mayer[14], Surendra Singh[15]

Transition Status of Specific NDE of AM Tasks to MSFC

Bring NASA strength and depth to the table for Additive Manufacturing

- Core MSFC Team:
  - Walker, Lanigan, Wells, and West
- Transition in progress for NASA MSFC to lead the following AM activities: (done/in progress) – all may require funding for MSFC
  - Lead NDE portion of 1st ASTM Additive Manufacturing Center of Excellence Workshop on March 25, 2019 (led by MSFC, EWI and Auburn University)
  - Participate/lead NDE portion of Oct. 8-9, 2019 Symposium on Structural Integrity of Additive Manufactured Parts (Washington, D.C.)
  - Determine value to NASA of draft NDE-related standards on Seeded Defects (F42 WK56649), In-Situ Monitoring (E07.10 WK62181), CT Metrology (E07.01 WK61161 and WK61974), and Data Fusion (current E07.10 action)
    - Lead efforts for effect-of-defect, Probability of Detection, and NDE inspection categories, especially for fracture critical metal spaceflight hardware. NASA MSFC is working with NIST (Kim), linkage also made with the MTC (Dutton).
  - Lead future ASTM classes on NDE of metal AM hardware (transferred to Steve James, formerly of Aerojet Rocketdyne)
  - Lead June 3rd NDE of AM discussions at E07.10 Taskgroup meetings
  - Lead NASA NDE discussions with JAXA and ESA

1st ASTM AM COE Workshop
March 25, 2019
(transitioned to MSFC)

ASTM INTERNATIONAL
Helping our world work better

1st ASTM Additive Manufacturing Center of Excellence Workshop

March 25, 2019

Auburn Marriott
Opelika Resort & Spa
at Grand National
Opelika, AL

www.astm.org

CENTER of EXCELLENCE
RESEARCH TO STANDARDS

AUBURN UNIVERSITY

EWI
We Manufacture Innovation

mtc

NAMIC
NATIONAL ADDITIVE MANUFACTURING INNOVATION CLUSTER

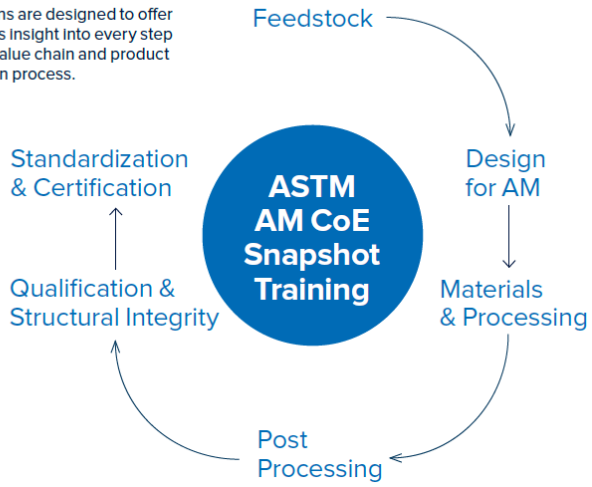
NASA

NIAR

1st ASTM AM COE Workshop/March 25, 2019

Session Topics

The sessions are designed to offer participants insight into every step in the AM value chain and product qualification process.



Agenda

7 a.m.	Breakfast
	Feedstock
8 a.m.	Powder Specification *Nick Weeks, LPW/Carpenter Additive*
9:30 a.m.	Powder Characterization *Steven Hall, The MTC*
10:15 a.m.	Break
	Design for AM
10:30 a.m.	Design for AM *David Rosen, Georgia Tech University/ SUTD*
	Materials & Processing
11:15 a.m.	Materials & Process Development *Frank Medina, EWI/UTEP*
11:45 a.m.	Lunch
12:45 p.m.	Process Qualification *Doug Wells, NASA*
	Post Processing
1:30 p.m.	Post Processing *Alex Kitt, EWI*
2 p.m.	Non-Destructive Evaluation & Inspection *James Walker, NASA Marshal Space Flight Center*
2:45 p.m.	Break
	Qualification & Structural Integrity
3 p.m.	Mechanical Characterization of AM Metallic Materials *Nima Shamsaei, Auburn University*
3:45 p.m.	Mechanical Characterization of AM Non-Metallic Materials *Rachael Andrulonis, NIAR*
4:15 p.m.	Break
	Standardization & Certification
4:30 p.m.	AM Standardization *John Slotwinski, John Hopkins University*
5 p.m.	Aerospace Certification *Michael Gorelik, FAA*
5:30 p.m.	Medical Certification *Matthew DiPrima, FDA*
6 p.m.	Social Networking Event

4th ASTM Symposium on Structural Integrity of AM Parts October 8-10, 2019

(transitioned to MSFC)

4th ASTM Symposium on Structural Integrity of AM Matls. and Parts

This event will provide a forum for the exchange of ideas regarding the structural integrity of materials and components fabricated using additive manufacturing with a focus on the lack of industry standards, design principals, as well as qualification and certification criteria. This event is designed for professionals within the AM community including industrial (aerospace, medical, automotive and defense), academic, government and regulatory.

To participate in the symposium, authors must submit a 200-250 word preliminary abstract using the online Abstract Submittal Form, ***no later than May 15th, 2019.***

2019 Scientific & Technical Committee (STC):

Anil Sachdev, General Motors
Ben Dutton, MTC
Charles Park, Boeing
Chee Kai, NTU
Chris Holshouser, NIAR
Doug Wells, NASA Marshall
Filipo Berto, NTNU
Frank Medina, EWI
Johannes Gumpinger, ESA
Matthew DiPrima, FDA
Matthew Donovan, Oerlikon
Michael Gorelik, FAA
Mohsen Seifi, ASTM Interntl.
Nik Hrabi, NIST
Nima Shamsaei, Auburn Univ.
Rachael Andrulonis, NIAR
Rod McMillan, Johnson & Johnson
Stefano Beretta, Polytechnic of Milan
Steve Daniewicz, Univ. of Alabama
Thomas Niendorf, Univ. of Kassel
Tony Thornton, Micromeritics

Erin Lanigan, Doug Wells, and Brian West of MSFC and Rick Russell of the NESC participated in the 2018 3rd Annual Symposium

NDE of AM Courses and Webinars
(transitioned to MSFC, LaRC, and others)

Quality Engineering Webinar (Waller):[1]

May 30, 2017

[1] Satern Course SMA-DFS-011, Sponsoring organization: NASA Safety Center Quality Engineering. *Hosts*: Mike Lipka and Gene Monroe

Other presentations given by D. Wells and D. Jegley

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170005627.pdf

ASTM NDE of AM Webinar (Waller, James):[2]

Feb. 6 and 13, 2018 (Waller)
Apr. 9 and 16, 2019 (James)

[2] New content presented by S. James (Aerojet Rocketdyne, ret'd.) in April

2018 content:
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180001858.pdf

NASA Safety Center Course (Burke and Wells):[3]

Dec. 11, 2018

[3] Satern Course SMA-QE-WBT-202, Customer: Michael P. Kelly, NSC Quality Engineering Technical Discipline Team Lead

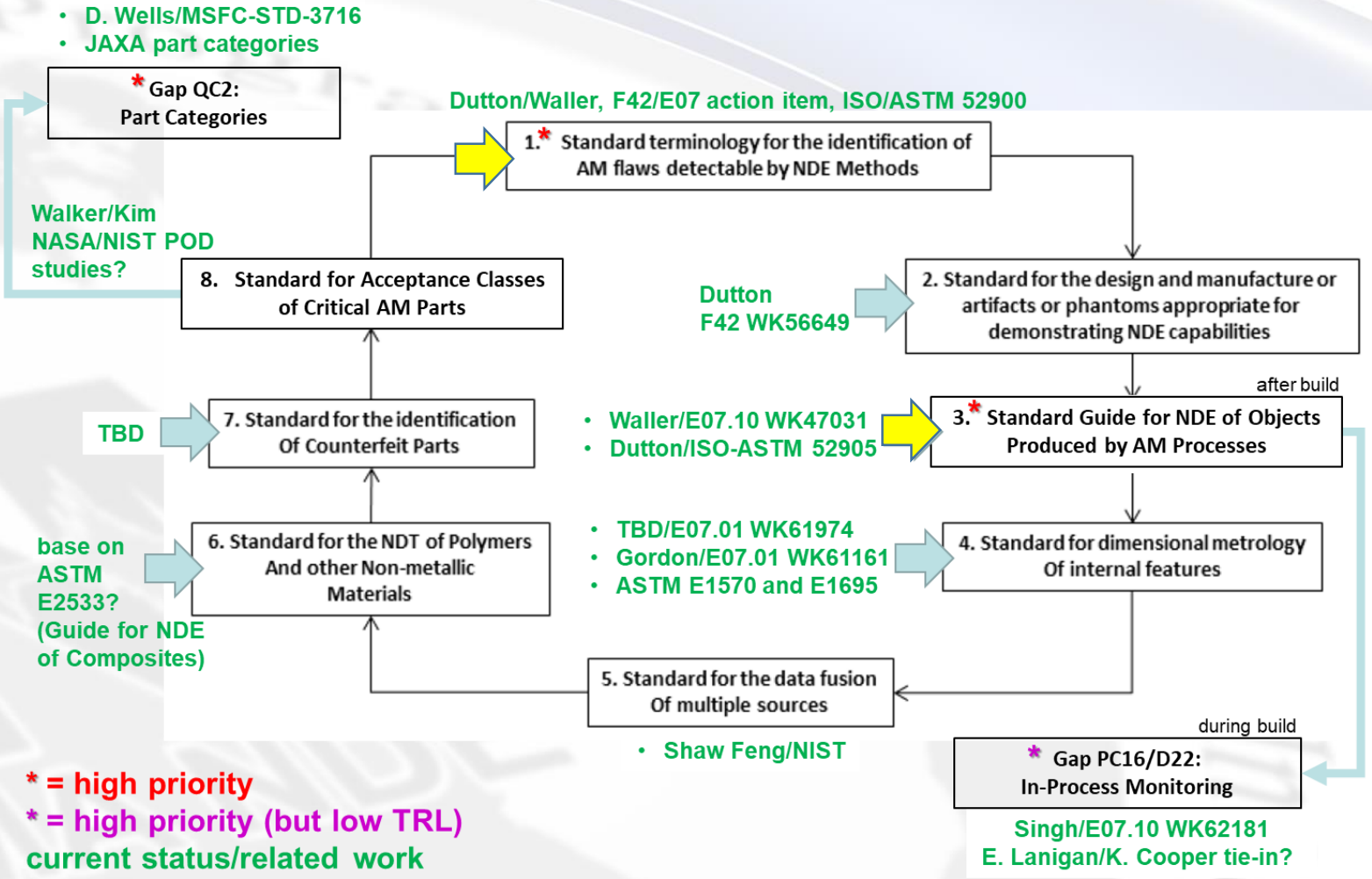
Additive Manufacturing
NDE Voluntary Consensus Standards
(being transitioning to MSFC)

NDE Voluntary Consensus Standards (Additive Manufacturing)

- 89 standards gaps identified
  - 26 design gaps
  - 7 precursor materials gaps
  - 17 process control gaps
  - 6 post-processing gaps
  - 5 finished materials gaps
  - **8 NDE gaps**
  - 15 Q&C gaps
  - 8 maintenance gaps
- Gaps were ranked low (19), medium (51), or high (19) priority depending on criticality, achievability, scope, and effect.

https://www.ansi.org/standards_activities/standards_boards_panels/ amsc/amsc-roadmap

NDE of AM Standards In Progress or Planned



https://www.americamakes.us/america-makes-ansi-publish-version-2-0-standardization-roadmap-additive-manufacturing/

Agenda for Denver June 2019 E07 Taskgroup Meeting

- Upcoming June 3, 2019 meeting will focus on Round Robin testing close-out, anything MSFC wants to cover related to AM, WK47031 balloting, and upcoming PMC/COPVs standard revisions (E2981, E2982, and E2533).

AGENDA

ASTM E07.10, Subcommittee on Specialized NDT Methods
TASK GROUP ON NDT OF AEROSPACE MATERIALS

Monday, January 21, 2019
11:00 am to 2:00 pm EST (GMT-05:00)
Fort Lauderdale, FL

11:00 **Call Meeting to Order; Introductions around the table, plus roll call for remote WebEx meeting attendees (Jess Waller, NASA WSTF, Las Cruces, NM)**

11:05 **Round Robin Testing**

- 11:05 Summary of America Makes/ANSI NDE of AM Standardization Roadmap and Associated Activities Including Round Robin Testing (**Jess Waller**)
- 11:15 Invited Talk: *Towards the Detection of Defects and their Effect on Mechanical Properties of AM Components*, **Griff Jones, Penn State University, CIMP-3D**
- 11:45 Future Talks (tentative)
  - *CT Research Activities and Development of POD Curves for AM Parts*, **Felix Kim, NIST**
  - *Data Fusion of In-situ and Ex-situ Measurements for Additive Manufacturing*, **Shaw Feng, NIST**
  - *CT Round Robin Testing*, **Anton Du Plessis, Stellenbosch University, Central Analytical Facilities**
  - *Neutron Tomography of Ti-6Al-4V Porosity Bars*, **Anna Paradowska, Australian Centre for Neutron Scattering**
  - *Concept Laser CT Physical Reference Standards Results*
    - **Eric Karlan, UTAS/Collins** (findings in export control)
    - **Justin Jones, NASA GSFC** (deferred to a later date)
    - **Cliff Bueno, GE Global Research** (current custodian)
- 11:55 Future Meetings
  - 1st ASTM Additive Manufacturing Center of Excellence Workshop, Opelika, AL, March 25, 2019 (**sponsored by ASTM, Auburn University, EWI, NASA MSFC and others**)
  - 4th ASTM Symposium on the Structural Integrity of Additive Manufactured Parts, Washington DC, October 15-17, 2019 (**sponsored by ASTM F42, E08, and E07**)

12:00-1:00 **Lunch on your own**

1:00 **ASTM E07.10 NDE of AM standard**

- WK47031 *Guide for Nondestructive Testing of Metal Additive Manufactured Aerospace Parts After Build* (POC: Jess Waller)
  - 18-05 balloting results (closed 1/11/2019):
    - Negatives (4)
    - Comments (6)
  - Future balloting

1:40 **Other ASTM Standard with relevance to NDE/Additive Manufacturing**

- ASTM F42.01/ISO TC 261 JG59 WK56649 *Guide for Intentionally Seeding Flaws in Additive Manufactured Parts* (POC: Ben Dutton)
- ASTM E07.01 standards
  - ASTM WK61161 *New Practice for Volumetric Computed Tomographic (CT) Examination Using Digital Detector Arrays* (POC: Trey Gordon, SpaceX)
  - ASTM WK61974 *New Practice for characterization of computed tomography systems for dimensional measurement* (POC: Thomas Wentzel, YXLON)

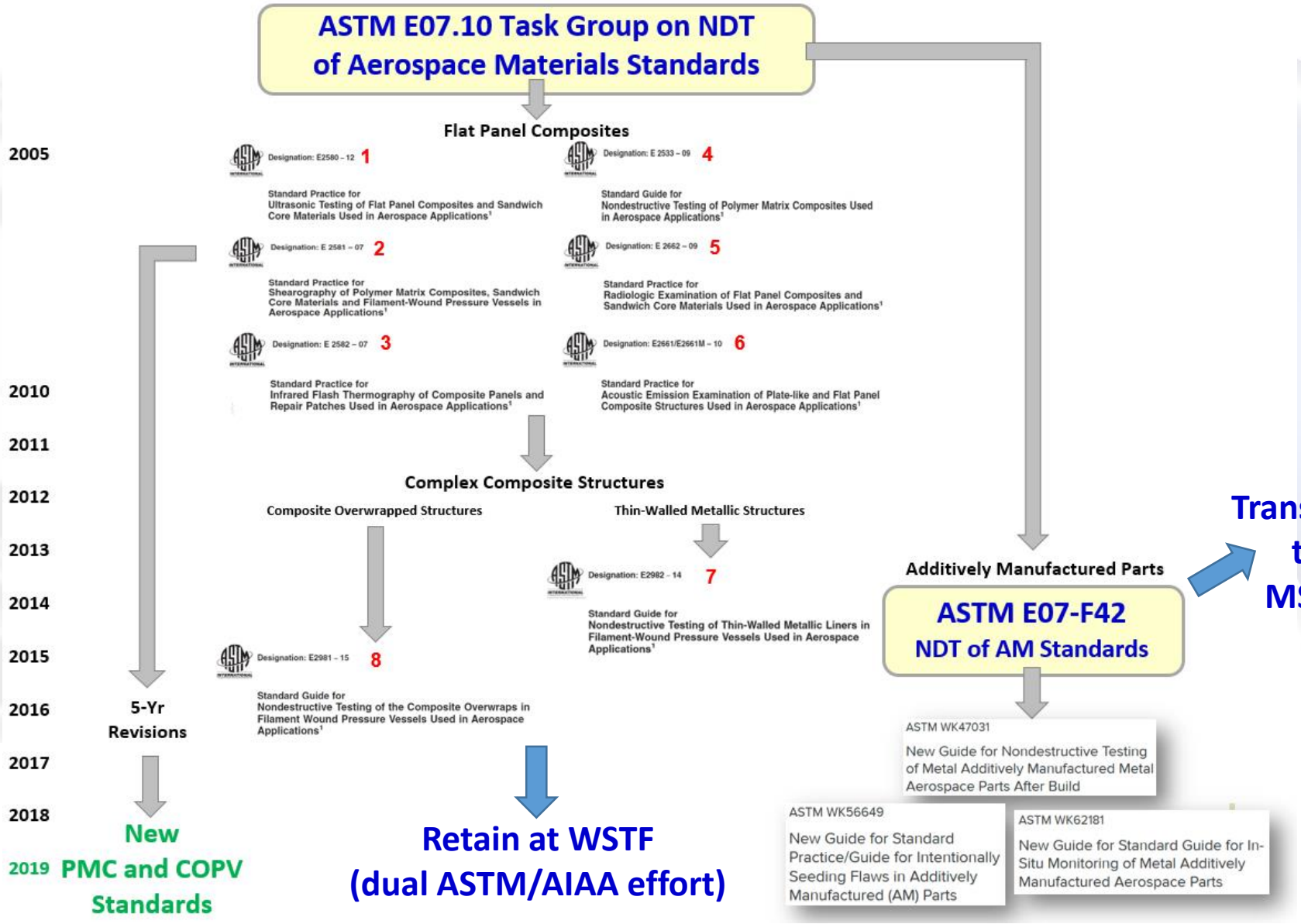
1:45 **Status on E07 Flat Panel Composite and Composite Overwrapped Pressure Vessel (COPV) Standards**

- **Flat Panel Composite Standards**
  - Status: **Ballot Action Required**
  - E2582-07(2014) *Practice for Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications* (POC: Engels (E07.10))
    - Status: **Ballot Action Required**
- **COPV Standards**
  - E2982-14 *Guide for Nondestructive Testing of Thin-Walled Metallic Liners in Filament-Wound Pressure Vessels Used in Aerospace Applications* (POC: Waller (E07.10))
    - Status: **Ballot Action Required**

1:50-2:00 **Break**

NDE Voluntary Consensus Standards Summary

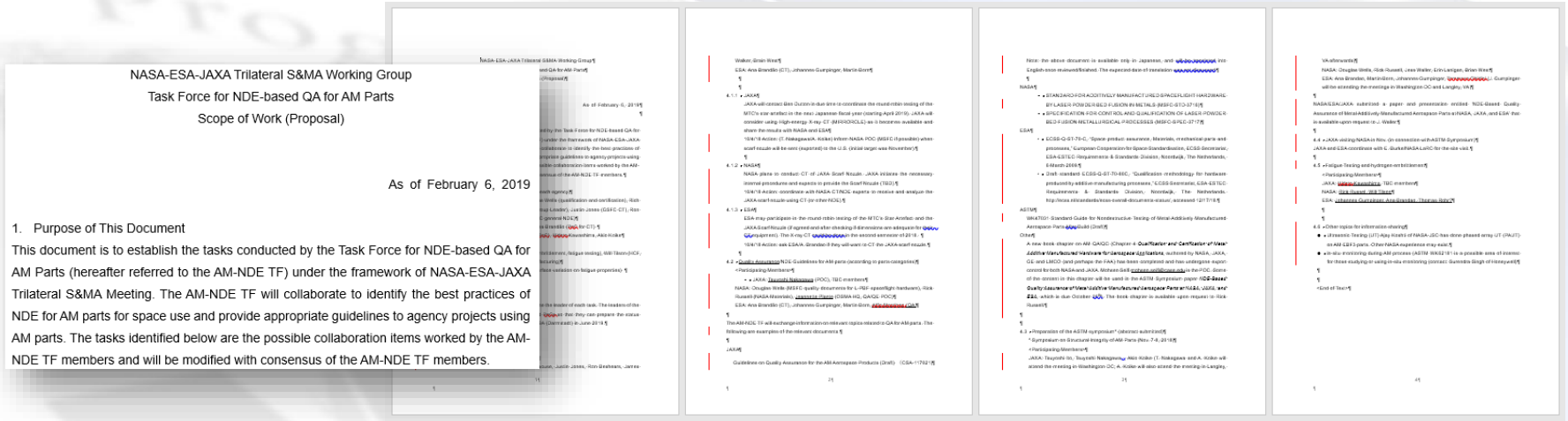
- 14-year effort funded by OSMA and the NTSPO



NASA-JAXA-ESA Trilateral Collaboration on Additive Manufacturing

(transition to MSFC?)

NASA/ESA/JAXA Statement of Work (Feb. 2019):



NASA-ESA-JAXA Trilateral S&MA Working Group
Task Force for NDE-based QA for AM Parts
Scope of Work (Proposal)

As of February 6, 2019

1. Purpose of This Document

This document is to establish the tasks conducted by the Task Force for NDE-based QA for AM Parts (hereafter referred to the AM-NDE TF) under the framework of NASA-ESA-JAXA Trilateral S&MA Meeting. The AM-NDE TF will collaborate to identify the best practices of NDE for AM parts for space use and provide appropriate guidelines to agency projects using AM parts. The tasks identified below are the possible collaboration items worked by the AM-NDE TF members and will be modified with consensus of the AM-NDE TF members.

Annual Trilateral/TRISMAC meeting on June 7, 2018:

NDE Qualification of Metal Additive Manufactured Spaceflight Hardware

OSMA Trilateral Meetings - NASA

Additive Manufacturing at ESA

Martin Born
Product Assurance & Safety (PA&S) Manager at ESA for European Data Relay Satellite System (EDRS)

June 7th, 2018

ESA UNCLASSIFIED - For Official Use

European Space Agency

JAXA Activities on Quality Assurance of AM Parts for Space Use

June 7th, 2018
Safety and Mission Assurance Department
Japan Aerospace Exploration Agency

Trilateral NASA-ESA-JAXA Collaboration@Kennedy Space Center

Thank you!
with gratitude and humility

Gratitude is marked by a sense that one has benefited from the actions of others.
Humility is characterized by low self-focus, secure sense of self, and increased valuation of others.

Back-ups

Background

- Ongoing voluntary consensus organization (VCO) standards effort managed under the jurisdiction of ASTM Committee E07 on NDT can be subdivided into four areas:
  - Polymer matrix composite flat panels (E2580, E2581, E2582, E2661, E2662, and E2533)
  - Composite overwrapped pressure vessels (E2981 and E2982)
  - Metal structures (E07.07 ECT of thin-walled metals liners, E07.05 neutron digital radiography of fairings and frangible joints) (possible standards not pursued)
  - Metal additively manufactured parts:
    - E07 WK47031 (NDE of AM) POC: Waller
    - E07 WK62181 (*in-situ* monitoring) POC: Singh (Honeywell)
    - F42 WK56649 (seeded defects) POC: ~~James,~~ Dutton (MTC)

FY19-20 NDE Voluntary Consensus Standards Schedule

Current Schedule

- **Balloting of NDE of AM Standard** — **May 2019**
  - **WK47031 (NDE of metal AM Aerospace Parts)**
- **June Committee Meeting (attend remotely if necessary)** — **June 2019**
  - **Discuss above balloting results**
  - **Register E2981 work item (NDE of COPV composite overwraps)** — AM
- **Balloting of COPV Standard** — **July 2019** — no AM
  - **E2982 WK67293 (NDE of metal COPV liners)**
- **Future balloting of E07 E2981, E2982, and E2533 (& G04 G114)** — **(requires funding)**
- **January E07 Committee Week Meeting (& Apr. G04 telecons)** — **January 2020 (requires funding)**
- **June E07 Committee Week Meeting (& Oct. G04 telecons)** — **June 2020 (requires funding)**

The NASA Technical Standards Program Office is a possible alternate source for General VCO Support for the above

NDE Voluntary Consensus Standards

- Biannual E07.10 Taskgroup meetings held each Jan/June.
- Support and interest from industry, government, and academia has been excellent (50+ members per meeting, see next 3 slides).
- Taskgroup meetings have split time between PMC/COPV and AM standards. Except for AM Round Robin Testing close-out and WK47031 balloting and adoption, future meetings will focus on NDT of PMCs/COPVs exclusively.
- The plan is to have NASA MSFC step into role of interfacing with ASTM Committee E07 for AM standards (James Walker intends to join E07 to represent NDE of AM standardization activities).
- J. Waller (technical POC for each) still on hook to coordinate balloting of:
  - E2533 (PMC Guide)
  - E2981 (COPV composite overwrap Guide)
  - E2982 (COPV composite overwrap Guide)
- Ed Generazio (since 2005) and Paul Gill (split effort with Ed from ca. 2005-2007) provided generous support for Committee E07 involvement:
  - 2005-2012: George Matzkanin E07.10 Task Group chair
  - 2012-present: Jess Waller E07.10 Task Group chair
- Both E07 and the NESC NDE TDT represent great opportunities for NASA to engage with industry NDE experts.
  - E07 membership currently has over 500 members with roughly 100 members attending each of the biannual meetings

PMC and COPV standards

Designation: E2580 – 12

2nd 5-Year Reapproval Completed 2017

Standard Practice for
Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications[1]

Designation: E2581 – 14

5-Year Reapproval Completed 2014

Standard Practice for
Shearography of Polymer Matrix Composites and Sandwich Core Materials in Aerospace Applications[1]

Designation: E2582 – 07 (Reapproved 2014)

5-Year Reapproval Completed 2014

Standard Practice for
Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications[1]

Designation: E2982 – 14

Adopted in 2014

Standard Guide for
Nondestructive Testing of Thin-Walled Metallic Liners in Filament-Wound Pressure Vessels Used in Aerospace Applications[1]

Designation: E2661/E2661M – 10

5-Year Reapproval Completed 2015

Standard Practice for
Acoustic Emission Examination of Plate-like and Flat Panel Composite Structures Used in Aerospace Applications[1]

Designation: E2662 – 09

5-Year Reapproval Completed 2015

Standard Practice for
Radiologic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications[1]

Designation: E2533 – 09

5-Year Reapproval Completed 2016, edited 2017

Standard Guide for
Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications[1]

Designation: E2981 – 15

Adopted in 2015

Standard Guide for
Nondestructive Testing of the Composite Overwraps in Filament Wound Pressure Vessels Used in Aerospace Applications[1]

PMC and COPV standards

Designation: E2580 – 12

2nd 5-Year Reapproval Completed 2017

Standard Practice for
Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications[1]

Designation: E2581 – 14

2nd 5-Year reapproval Due (Newman)

Standard Practice for
Shearography of Polymer Matrix Composites and Sandwich Core Materials in Aerospace Applications[1]

Designation: E2582 – 07 (Reapproved 2014)

5-year revision begun WK66824 (E07.10)

Standard Practice for
Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications[1]

Designation: E2982 – 14

5-year revision begun WK67293 (Waller)

Standard Guide for
Nondestructive Testing of Thin-Walled Metallic Liners in Filament-Wound Pressure Vessels Used in Aerospace Applications[1]

Designation: E2661/E2661M – 10

5-Year Reapproval Completed 2015

Standard Practice for
Acoustic Emission Examination of Plate-like and Flat Panel Composite Structures Used in Aerospace Applications[1]

Designation: E2662 – 09

5-Year Reapproval Completed 2015

Standard Practice for
Radiologic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications[1]

Designation: E2533 – 09

5-Year Reapproval Completed 2017, edited 2019

Standard Guide for
Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications[1]

Designation: E2981 – 15

5-year revision begun WK TBD (Waller)

Standard Guide for
Nondestructive Testing of the Composite Overwraps in Filament Wound Pressure Vessels Used in Aerospace Applications[1]

Customers, Products

- Customers:
  - For COPVs/PMCs: SpaceX & Boeing/Commercial Crew Program: Kathy Lueders, Commercial Crew Program Manager, Gateway Program: Orion SLS EM-1, EM-2, and moon missions: Dan Hartman, Gateway Program Office Lead, NESC: Bill Prosser, NESC NDE Technical Fellow, NESC: Lorie Grimes-Ledesma, Composite Pressure Vessel Working Group Leads, Human Spaceflight: Nate Greene, NASA-JSC, Pressure Systems/Fracture Technical Discipline Lead, Orion MPCV and ESA crew modules: Ian Juby, Pressure Systems Engineer for COPVs, Boeing CST-100/ULA Altas 5 rocket: Aaron Laney, Pressure Systems Engineer for COPVs.
- FY18-FY19 Products:
  - NASA Safety Center course on NDE-based Qual &Cert of L-PBF AM Hardware: Dec. 11, 2018
  - NASA-JAXA-ESA AM Collaboration telecons, TRISMAC presentation, and draft Statement of Work
  - Co-chaired 3rd ASTM Symposium on Structural Integrity of AM Parts (NDE portion): Nov. 6-8, 2018
  - QLF and JAPC presentations (QA/QE audience): March 15, 2018 and Feb. 7, 2018
  - 1 book chapter on Qual & Cert of L-PBF Metal AM Aerospace Hardware
  - 1 magazine article on CT of metal AM Parts
  - 5 peer-reviewed NDE of AM articles (4 ASTM STP 1620 publications + 1 ASTM MPC publication)
  - Transfer of NDE of AM tasks to NASA MSFC (primarily James and Erin)
  - ASTM Charles W. Briggs Award for continuous and outstanding contributions to the work of Committee E07 on Nondestructive Testing: March 2018
- Future NDE Standards Products:
  - One new standard (WK47031) (accomplish with existing funding)
  - Two 5-year revisions of current NDE of PMC/COPV standards (E2981, E2982) and technical editing of E2533 based on E2981, E2982 revisions (requires new funding)

2019 Products (Publications):

- du Plessis, A. and Waller, J. M., "Simple and standardised X-ray CT testing in metal Additive Manufacturing," *Metal AM* 4(4), 87-96, Winter 2018. https://issuu.com/inovar-communications/docs/mam_winter_2018_sp?e=32443561/66482405
- Dutton , B., Vesga, W., Waller, J., James, S., and Seifi., M., "Additive Manufacturing Defect Formation and NDE Detectability," in *ASTM Symposium on Structural Integrity of Additive Manufactured Parts*, ASTM STP 1620, M. Seifi and N. Shamsaei, Eds., ASTM International, West Conshohocken, PA (in press).
- S. James, J. Waller, M.-C. Ebert, H. Gong, E. Biedermann, K. LaCivita, J. Brausch, T. Nakagawa, C. Peitsch, B. Trethewey, M. White, E. Ginzel, C. Kretzer, T. Mayer, S. Singh, and J. Middendorf, "Representative NDE Round Robin Results on Metal Additively Manufactured Test Parts and Physical Reference Standards," in *Materials Performance and Characterization,* ASTM International (in preparation).
- Na, J. K, Middendorf, J., Lander, M., Waller, J. M., "Nondestructive Evaluation of Programmed Defects in Ti-6Al-4V L-PBF ASTM E8-compliant Dog-bone Samples," in ASTM Symposium on Structural Integrity of Additive Manufactured Parts, ASTM STP 1620, M. Seifi and N. Shamsaei, Eds., ASTM International, West Conshohocken, PA (in press).
- Livings, R. A., Biedermann, E. J., Wang, C., Chung, T., James, S., Waller, J. W., Volk, S., Krishnan, A., Collins, S., "Nondestructive Evaluation of Additive Manufactured Parts Using Process Compensated Resonance Testing," in *ASTM Symposium on Structural Integrity of Additive Manufactured Parts*, ASTM STP 1620, M. Seifi and N. Shamsaei, Eds., ASTM International, West Conshohocken, PA (in press).
- Waller, J., Rojdev., K., Peters, B., Shariff, K., Litteken, D., Hagen, R., Valle, G., Nichols, C., "Simulated Space Radiation Effects on Inflatable Habitat, Composite Habitat, Space Suit, and Space Hatch Materials," *WSTF-IR-1250-001-18, N*ASA Johnson Space Center White Sands Test Facility, Las Cruces, New Mexico (in review).
- Waller, J.M., Nichols, C. T., Burke, E. R., Wells, D. N., Brandão, A. D., Gumpinger, J., Born, M., Ghidini, T., Nakagawa, T., Koike, A., Mitsui, M., Itoh, T., "NDE-Based Quality Assurance of Metal Additive Manufactured Aerospace Parts at NASA, JAXA, and ESA," in *ASTM Symposium on Structural Integrity of Additive Manufactured Parts*, ASTM STP 1620, M. Seifi and N. Shamsaei, Eds., ASTM International, West Conshohocken, PA (in press).
- Russell, R., Wells, D., Waller, J. M., Poorganji, B., Ott, E., Nakagawa, T., Sandoval, H., Shamsaei, N., Seifi. M., "Qualification and Certification of Metal Additive Manufactured Hardware for Aerospace Applications," Chapter 3, in *Additive Manufacturing for the Aerospace Industry*, Boyer and Froes, Eds., Elsevier, December 2019. https://www.elsevier.com/books/additive-manufacturing-for-the-aerospace-industry/froes/978-0-12-814062-8

Round Robin Testing of AM Parts

ASTM WK47031 Round Robin Testing

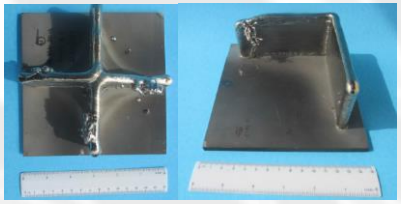
Coordinated by S. James and J. Waller

Electron Beam Freeform Fabrication (EBF^3)

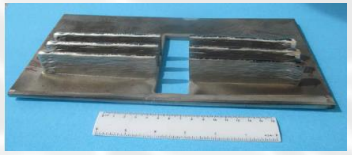
NASA LaRC

Inconel 625 on copper

Ti-6Al-4V (4)



SS 316

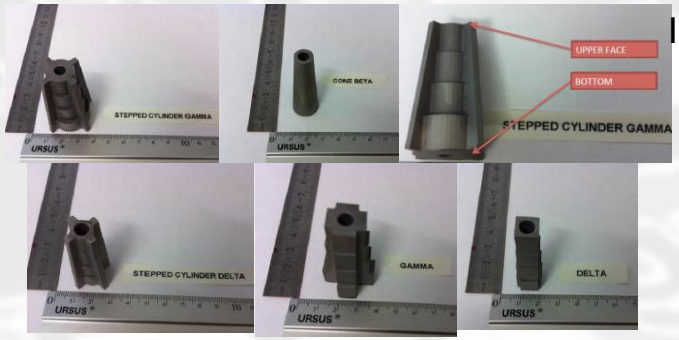


Al 2216

Laser-PBF (L-PBF)

Concept Laser Inconel 718 inserts (6) w/ different processing history

Concept Laser Inconel 718 prisms for CT capability demonstration

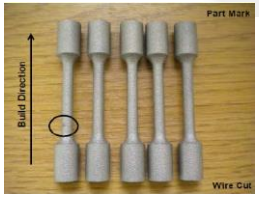


Gong/Univ. of Louisville

Ti-6Al-4V bars

Airbus

Al-Si-10Mg dog bones



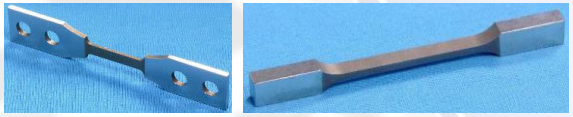
Laser-PBF (L-PBF)

Incodema3D

Al-Si-10Mg cylinders

UTC/Southern Research

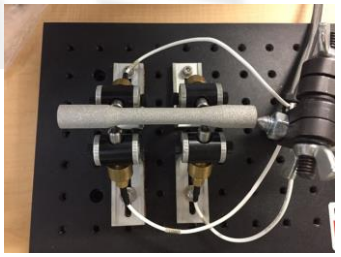
Inconel 718 and Ti-6A-4V dogbones



Electron Beam-PBF (E-PBF)

CalRAM

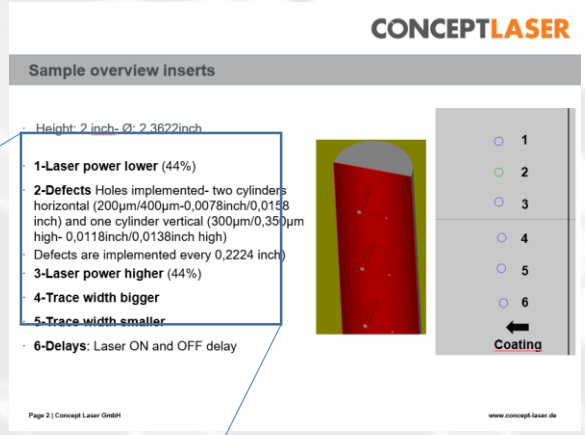
Ti-6Al-4V dogbones

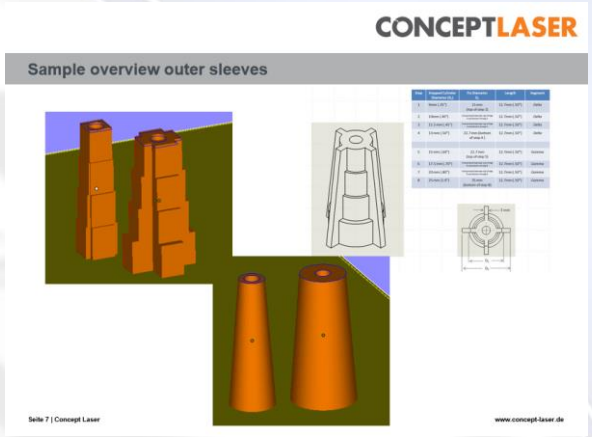


Characterized to date by various NDE methods (CT, DIC, PT, PCRT, RT, UT)

Concept Laser/GE CT Capability Demonstration Samples

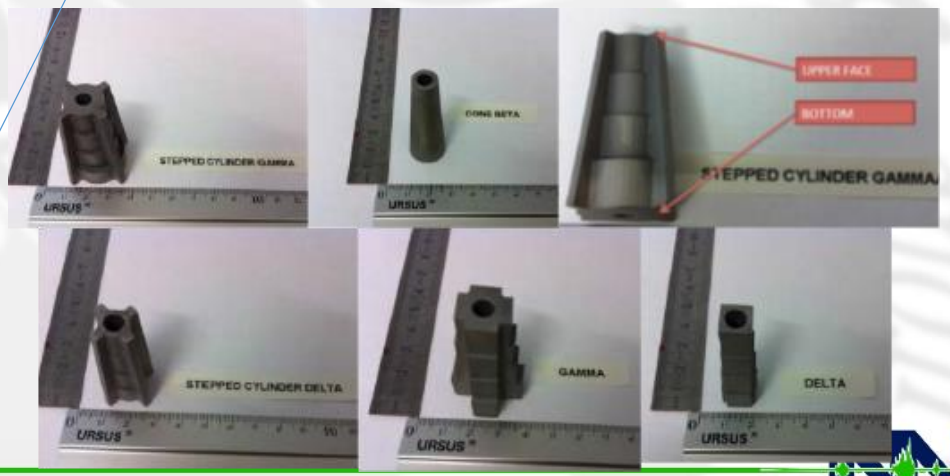
Inconel® 718 inserts and sleeves fabricated in early 2016 and distributed to participants with CT capability





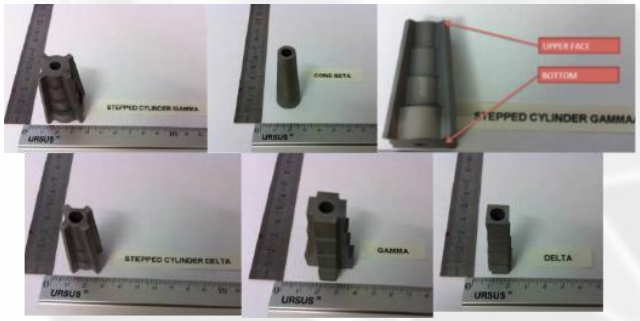
Inserts

- **1-Laser power lower** (44%)
- **2-Defects** Holes implemented- two cylinders horizontal (200µm/400µm-0,0078inch/0,0158 inch) and one cylinder vertical (300µm/0,350µm high- 0,0118inch/0,0138inch high)
- Defects are implemented every 0,2224 inch)
- **3-Laser power higher** (44%)
- **4-Trace width bigger**
- **5-Trace width smaller**
- **6-Delays**: Laser ON and OFF delay



CY19 Concept Laser/GE CT Sample Distribution

- Inconel® 718 inserts & sleeves fabricated in Jan. 2016 and distributed to participants
- CT results on this and other samples summarized in paper posted on WK47031 Collaboration Area



- **1-Laser power lower** (44%)
- **2-Defects** Holes implemented- two cylinders horizontal (200µm/400µm-0,0078inch/0,0158 inch) and one cylinder vertical (300µm/0,350µm high- 0,0118inch/0,0138inch high)
- Defects are implemented every 0,2224 inch)
- **3-Laser power higher** (44%)
- **4-Trace width bigger**
- **5-Trace width smaller**
- **6-Delays**: Laser ON and OFF delay

Europe; Fraunhofer Development Center X-ray Technology, Yxlon, GE (Europe)

Japan; JAXA/Kobelco/NDI Corp.

Planned Evaluation (9)

N America; NASA MSFC, UTAS, JHU APL, NASA GSFC, GE Global, Pratt & Whitney, NSI, LMCO, Pinnacle X-ray, Alloyweld Inspection, EWI

So. Africa, Europe; Stellenbosch Univ., Visiconsult, ESA

Participation Rules

Samples will be shipped as one set
1 month loan period
Present findings at WK47031 Link Call
Ship to next participant on list

Schedule

Affiliation	contact	finish date
UTAS	Karlen	Feb-18
JHU-APL	Peitsch	Jun-18
NASA GSFC	Jones	Sep-18
GE Aviation	Bueno	Oct-18
Pratt & Whitney	Warner	Feb-19
NSI	Brinkhoff	Mar-19
LMCO	Barnes, Boss	2019
Pinnacle X-ray	Gormley	2019
Alloyweld Inspection	Kleven	2019
EWI	Kitt, Brooks	2019
Stellenbosch Univ.	Du Plessis	2019
Visiconsult	Schulenburg	2019
ESA	Brandao	2019
Return to Concept Laser/GE Additive	Ebert	EOCY19

List with addresses will accompany the samples

Attendance at Ft. Lauderdale January 2018 E07 TG Meeting

Guide for NDT of Additive Manufactured Aerospace Components
ASTM E07.10 Task Group on NDT of Aerospace Materials
FORT LAUDEDALE, FL
Monday, January 22, 2018
MINUTES

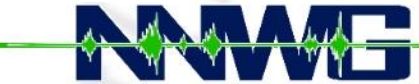
Attendees:

Present:

1Mark Carlos	Mistras Group
Patrick Carlson	NSI
Terry Clausing	Virtual Spectrum
John Crnko	Analytical Services, Inc.
5Heather Dreiling	Arconic
Lionel Gay	Safran
Denny Gorczyca	Pratt & Whitney
Matt Gormley	Pinnacle X-ray Solutions
Trey Gordon	SpaceX
10Richard Gostautas	Mistras Group
John Flaherty	Fujifilm
Patrick Howard	GE Aviation
Chad Henry	GKN Aerospace
Ryan Johnson	Fujifilm
15David Johnson	GE Aviation
Sean Larkin	Lickenbrock Technologies
Vic Marconcini	Aerojet Rocketdyne
Bill McKessy	Arconic Howmet
Alan Metzel	Northrup Grumman
20Jim Mitchell	Structural Diagnostics
Jim Neal	Fujifilm
Jeff Pryor	ORNL
Stephen Rice	GE Aviation
Lennart Schulenburg	VisiConsult X-ray
25Surendra Singh	Honeywell Aerospace
Ed Stenger	ULA
Richard Stiff	Aerojet Rocketdyne
Pat Thompson	Honeywell Aerospace
Iirka Virkkonen	Trueflaw
30Jess Waller	NASA WSTF HX5

Remote:

1Devin Barnes	LMCO
Eric Biedermann	Vibrant Corporation
Mitch Boss	LMCO
Janelle Chambers	Southern Research
5David Craig	Pratt & Whitney CA
Jeff Donahue	Spacex.com
Matt Donovan	Oerlikon
Ben Dutton	MTC
Donna Dykeman	Granta Design
10Marie Ebert	GE
Andrew Good	Jesse Garants Assocs
Ben Green	NASA WSTF/Jacobs
Steve James	Aerojet Rocketdyne
Alex Kitt	EWI
15Muzibur Khan	NRC CNRC
J Kozub	Precision ADM
Greg Loughnane	UTC Dayton
Catalin Mandache	NRC CNRC
Rob Mason	CTC
20John Middendorf	UTC Dayton
Christopher Peitsch	JHU APL
Hank Phelps	LMCO
Keith Randolph	Aerojet Rocketdyne
M. Hashimi Rosli	MTC
25Evgueni Todorov	EWI
Scott Volk	Incodema3D
Peter Woolliams	NPL UK



Attendance at San Diego June 2018 E07 TG Meeting

Guide for NDT of Additive Manufactured Aerospace Components
ASTM E07.10 Task Group on NDT of Aerospace Materials
SAN DIEGO, CA
Monday, June 25, 2018
MINUTES

Attendees:

Present:

[1]Eric Biedermann	Vibrant Corporation
Nick Brinkoff	North Star Imaging
Justin Byers	Pratt & Whitney Canada
Pat Carlson	North Star Imaging
[5]Damaso Carreon	USAF NDI Program Office
Terry Clausing	Virtual Spectrum
Klaus Bavendiek	Yxlon Intl. GmbH
Duane Dominick	ATI Specialty Materials
Jim Engel	consultant
[10]Uwe Evert	BAM Berlin
Andy Ferro	GE Aviation
Patrick Howard	GE Aviation
Chad Henry	GKN Aerospace
[15]David Johnson	GE Aviation
Stewart Kleven	Alloyweld Inspection Co.
Thomas Maeder	Boeing
Bill Meade	Blue Origin
Joel Mohnacky	UTC Aerospace Systems
[20]Stephen Pflanz	Carestream NDT
Stephen Rice	GE Aviation
Tyler Ripperger	GE Aviation
Jason Robbins	Yxlon
Don Roth	Baker Hughes/GE Inspection
[25]Lennart Schulenburg	VisiConsult X-ray Systems
Ed Stenger	consultant
Peter Takunju	Arconic
Jess Waller	NASA WSTF HX5
Andy Washabaugh	Jentek Sensors
[30]Uwe Zsherpel	BAM Berlin

Remote:

[1]Andrea Arguelles	PSU CIMP3D
Ana Brandao	ESA
Adam Brooks	EWI
Thomas Chung	Northrup Grumman
[5]Christopher Kube	Univ. Nebraska at Lincoln
Anton Du Plessis	Stellenbosch University
Roger Engelbart	Boeing
Eric Fodran	Northrup Grumman
Griffin Jones	PSU CIMP3D
[10]Justin Jones	NASA GSFC
Felix Kim	NIST
Catalin Mandache	NRC CNRC
John Middendorf	UTC Dayton
Joeng Na	Wyle
[15]Christopher Peitsch	JHU APL
Scott Poveromo	Northrup Grumman
Phillip Riegler	Norsk Titanium
Evgueni Todorov	EWI
Bonnie Wang	Northrup Grumman
[20]Roxanne Warren	Norsk Titanium
Lynne Webster	Mitre

Attendance at Ft. Lauderdale January 2019 E07 TG Meeting

ASTM E07.10 Task Group on NDT of Aerospace Materials
FORT LAUDERDALE, FL
Monday, January 21, 2019
MINUTES

Attendees:

Present:

[1]Frederick Beck	TAC Tech. Instrument Corp.	Lennart Schulenburg	VisiConsult X-ray Systems
Justin Byers	Pratt & Whitney Canada	Surendra Singh	Honeywell Aerospace
Terry Clausing	Virtual Spectrum	[30]Kristy Straiton	ASTM
Michael Coulton	TAC Tech. Instrument Corp.	Peter Takunju	Arconic
[5]John Crnko	Analytical Services, Inc.	Chris Udell	Proceq SA Inc.
James Drechsel	Cummins Inc.	Michael White	Met-L-Chek
Joshua Ford	SpaceX	Zhan Zang	Iowa State
Robert Francoeur	Pratt & Whitney		
Matt Gormley	Pinnacle X-ray Solutions Inc.	Remote:	
[10]David Gray	Mitchell Laboratories	[1]Devin Barnes	LMCO
Harry Hahn	N/A	Ana Brandão	ESA
Bob Henchaor	Test Equipment Distributors	David Craig	Pratt & Whitney Canada
Chad Henry	GKN Aerospace	Carl Dekker	Met-L-Flo
Edward Hohman	Bell Helicopter Textron	[5]Jim Engel	consultant
[15]Patrick Howard	GE Aviation	Eric Karlen	UTAS
Lemna Hunter	Vibrant Corp. NDT	Ajay Krishnan	Incodema3D
Griff Jones (speaker)	PSU CIMP3D	Jason Jones	Moog Inc.
Stewart Kleven	Alloyweld Inspection Co.	Jason Kozub	Precision ADM
Frederick Kaiser	VisiConsult X-ray Systems	[10]Rob Mason	Concurrent Technol. Corp
[20]Matt Meade	Blue Origin	Bill Meade	Blue Origin
Alan Metzel	Northrop Grumman	Anne-Francoise Obaton	LNE/France
John Molinaro	Fujifilm	Tom Ott	Proceq USA Inc.
Adrian Mondragon	N/A	Christopher Peitsch	JHU APL
Jim Neal	Fujifilm Ndt Systems	[15]Gerben Sinnema	ESA
[25]Mark Pompe	WPTG	Scott Volk	Incodema3D
Tyler Ripperger	Baker Hughes/GE Inspection	Jess Waller (POC)	NASA WSTF HX5
Don Roth	Baker Hughes/GE Inspection	Bonnie Wang	Northrup Grumman